**Air temperature**

Thermometers should be read to an accuracy of 0.1 °C

## Sling or whirling psychrometer

KNMI  sling psychrometer (photo by M. Stam, KNMI)

DWD  sling psychrometer (photo Deutscher Wetterdienst)

The wick (free of grease and not contaminated by salt spray) must be moistened with distilled water, if this is not readily available, water from the condenser will generally be more suitable than ordinary fresh water. For preference the psychrometer observation is made to the windward side. Whirling or rotating the thermometers by hand at a controlled rate ensures the ventilation. Sling psychrometers lacking radiation shields for the thermometer bulbs should be shielded from direct insolation in some other way. Thermometers should be read at once after aspiration ceases because the wet-bulb temperature will begin to rise immediately, and the thermometers are likely to be subject to insolation effects. The wick should be changed regularly.

observer reading sling psychrometer (photo KNMI, circa 1960)

## Louvered screen

UK Marine Screen (photo by G. Allen, Met Office)

If a louvered screen is to be used, two should be provided, one secured on each side of the vessel, so that the observation can always be made to the windward side. In this way the thermometers can be completely exposed to the air stream and uninfluenced by artificial sources of heat and water vapor. As an alternative, a portable louvered screen can be used, being hung on whichever side is to windward, to gain the same exposure. The muslin and wick fitted to a wet-bulb thermometer in a louvered screen should be changed at least once a week and more often if it becomes dirty or contaminated by salt spray, if any spray has reached the instrument, the muslin and wick should be replaced by new ones. It is advisable to do this in any case after bad weather.

**Humidity**

Dew-point and relative humidity can be obtained from the readings of the air temperature (dry- bulb) and wet-bulb. If the wet-bulb reading is not available, dew-point and wet-bulb temperature can be obtained from the readings of the air temperature and relative humidity (if available)

**Computing dew-point**

This program computes the dew-point automatically if the air temperature and wet-bulb temperature (or air temperature and relative humidity) are available. The formulas used are given in ref.1, ref.2 and ref.3.

Ref.1: Guide to meteorological instruments and methods of observation; Sixth edition; WMO-No. 8

Ref 2: KNMI V-327 by Hafkenscheid; modified according to formula of saturated vapor recommended by CIMO-X

Ref 3: Handbook of Meteorological Instruments; Second edition; the Met Office UK.

**Wet-bulb reading sling psychrometer**

Note

- For convenience, the default 'state of wet-bulb' is 'wet-bulb not frozen' on this temperatures input page. If the wet-bulb is frozen please check the 'frozen wet-bulb' button.

**Wet-bulb reading marine screen**

During frost, when the muslin is thinly coated with ice, the readings are still valid because evaporation takes place from a surface of ice as freely as from one of water. If the muslin is dry it must be given an ice coating by wetting it slightly with ice-cold water, using a camel-hair brush or by other means. The water will usually take 10 to 15 minutes to freeze. Excess of water must not be used as it takes much longer to freeze and will also not give accurate readings. After the wetting of the muslin, the temperature generally remains steady at 0 °C until all the water has been converted to ice. It then begins to fall gradually to the true ice-bulb reading. No reading must be recorded until the temperature of the ice-bulb has fallen below of the dry-bulb and remains steady. Dry, windy weather may cause the ice to evaporate completely before the time of the next reading, in which case the procedure of wetting the bulb must be gone through again. The original coating of ice will give satisfactory results as long it lasts. It must be pointed out that supercooled water may exist on the wet-bulb at temperatures well below freezing point and that, if this is not noticed by the observer, serious errors will occur. The freezing can be started by touching the wet-bulb with a snow crystal, a pencil, or other object. (source: The Marine Observer's Handbook; Met Office UK)

Note

- For convenience the default 'state of wet-bulb' is 'wet-bulb not frozen' on this temperatures input page. If the wet-bulb is frozen please check the 'frozen wet-bulb' button.

**SST (Sea Surface Temperature)**

The temperature to be observed is that of the sea surface representative of conditions in the near-surface mixing layer underlying the ocean skin.

The sea-surface temperature should be very carefully observed. This is because, amongst other things, it is used to obtain the difference with air temperature, which provides a measure of the stratification of temperature and humidity and of other characteristics of the lower layers of maritime air masses. For these reasons, the temperature of a seawater thermometer should be read to 0.1 °C.

**SST methods of observation**

It has not been possible to adopt a standard device for observing sea surface temperatures on account of the great diversity in ship size and speed and of considerations of cost, ease of operation and maintenance. The temperature of the sea surface may be observed by:

a) Taking a sample of the sea-surface water with a specially designed sea-bucket.
b) Reading the temperature of the condenser intake water.
c) Exposing an electrical thermometer to the seawater temperature either directly or trough the hull.
d) Other.

The principal methods used for very many years have been (a) and (b). Studies of difference in temperature provided by the two methods have been made in which it is reported that intake temperatures average 0.3 °C greater than those measured by sea-bucket samples. As the speed and height of ships have increased, method (c) which gives the most consistent results has been more widely used. Of all these methods the condenser intake technique is the least desirable because of the very great care needed to obtain good results.

**SST sea buckets**

UK sea temp. bucket and sea thermometer (photo by G. Allen, Met Office)

DWD sea surface temperature measurement instrument  (photo Deutscher Wetterdienst)

A sea-bucket is lowered over the side of the ship, a sample of seawater is hauled on board and a thermometer is then used to obtain its temperature. The sample should be taken from the leeward side of the ship, and well forward of all outlets. The thermometer should be read as soon as possible after it has attained the temperature of the water sample. When not in use the bucket should be hung in a shady place to drain.

A sea-bucket should be designed to ensure that sea water can circulate through it during collection and that the heat exchange due to radiation and evaporation is minimum. The associated thermometer should have a quick response and be easy to read and should preferably be fixed permanently in the bucket. If the thermometer must be withdrawn for reading, it should have a small heat capacity and be provided with a cistern around the bulb of volume sufficient that the temperature of the water withdrawn with it does not vary appreciably during the reading. The design of bucket should be deemed adequate for the purpose by the Member recruiting the ship for observations.

Sea-buckets of good design (not simple buckets of canvas or other construction) can be expected to agree well over an extensive range of conditions. However, they are less convenient to use than instruments attached to the ship and their use is sometimes restricted by weather conditions.

**SST intake and tank thermometers**

The thermometer provided within the intake pipe when the ship is built is normally not suitable for the measurement of sea surface temperature. Thus, the Member recruiting the ship should, with the permission of the shipping company concerned, install a thermometer appropriate for the purpose. This should preferably be mounted in a special tube providing adequate heat conductivity between the thermometer bulb and the intake water.

When a direct-reading thermometer is installed in cramped conditions the observer should be warned of the possibility of error in his readings due to parallax. A distant-reading system with the display elsewhere (e.g. in the engine room or on the bridge) overcomes this problem. The observer should also be aware that for ships of deep draught, or when a marked temperature gradient exists within the sea surface layer, intake temperature readings usually differ considerably from those close to the sea surface. Finally, of course, the intake temperature should not be taken when the ship is stationary, for then the cooling water is not circulating.

**SST hull attached thermometers**


hull sensor (photo by Capt. H. Gale, Met Office)

Hull-attached thermometers provide a very convenient and accurate means of measuring sea-surface temperature. They are necessarily distant-reading devices, the sensor being mounted either externally in direct contact with the sea using a "through-the-hull” connection, or internally (the “limpet” type) attached to the inside of the hull. Both types show very good mutual agreement, with the ”through-the-hull” type showing a slightly quicker response.

**Marine Observers Handbook**

**Air temperature and humidity**

## THE MEASUREMENT OF TEMPERATURE AND HUMIDITY

The temperatures normally measured at sea for meteorology are those of the air, at the height of the bridge, and of the sea, just below its surface. Humidity, i.e. a measure of the evaporated water contained in the air, is also required, but as this is obtained by similar instrumentation, it is included under the same general heading.

*Thermometers*

Any device which measures temperature is a thermometer. There is a wide range of physical phenomena related to temperature, almost any one of which may be used as a thermometer but the two which will be most frequently encountered are based on the expansion of a suitable substance with increased temperature and, similarly, the change of electrical resistance in a conductor. The simplest, cheapest and most commonly encountered device is the liquid-in-glass thermometer, the liquid employed being mercury or alcohol. Such a thermometer consists of a glass tube of very fine bore, at the end of which a bulb has been blown to act as a reservoir. The whole of the tube and bulb is filled with the chosen liquid at a high temperature and the open end of the tube is then sealed. On cooling, the liquid will contract until the tube is only partly filled by liquid, the exact point reached by the liquid being a measure of the temperature of the thermometer, and hence, under suitable conditions, of its surroundings, at any given moment. A scale may now be engraved on the tube, or thermometer stem, to allow actual temperature to be read.

The thermometer was invented at approximately the same time as the barometer. Galileo made a crude kind of thermometer in which the liquid was open to the air. True thermometers were first brought into general use by the Grand Duke Ferdinand II of Tuscany who is said to have possessed such instruments in 1654. The liquid used in these early thermometers was alcohol.

While mercury is the most satisfactory liquid for general thermometric use, thermometers intended for very cold climates contain pure alcohol. The reason for this is that mercury would solidify at the low temperatures of polar regions. Mercury freezes at about -39 ºC while alcohol freezes only at -130 ºC*,* though it becomes a thick liquid and therefore useless for thermometric purposes at -90 ºC.

Thermometers employing the electrical change of resistance due to temperature give no direct visual indication but must be placed in an electrical circuit which will enable the resistance and hence, from previous calibration, the temperature, to be measured. Such thermometers usually are constructed from a length of fine wire, drawn from a material such as platinum, tungsten, etc., which is ductile and will not corrode with time. For meteorological use, a spool of such wire is permanently enclosed in a small-diameter metal cylinder, for protection.

*Graduation* of *thermometers.* The earliest known graduation of a thermometer was that made in 1701 by Sir Isaac Newton, who divided the range of temperature between the freezing point of water and the temperature of the human body into twelve degrees.

Later scientists used as fixed points the temperature of a mixture of salt and ice, and the boiling point (at standard pressure) of water. The SI unit of temperature is the kelvin (symbol K), widely used in scientific work. It is defined as the fraction 1/273. 16 of the thermodynamic temperature of the triple point of water; the triple point of a substance being the pressure- temperature condition, unique for a given substance, at which the substance may exist in the solid, liquid or gaseous state. On this scale water freezes at 273.15 K and boils (at standard pressure) at 373.15 K. For normal use the Celsius (known as the centigrade) temperature (symbol ºC) has also been approved by the International Committee on Weights and Measures. It is defined as:

$$t=T-T_0$$

where $t$ = Celsius temperature, T= thermodynamic temperature in kelvins, and $T_0$ = 273.15 K. On this scale water freezes at 0 ºC and boils (at standard pressure) at 100 ºC. It is the official scale for the measurement of all meteorological temperatures.

The Fahrenheit scale (symbol ºF), once in general use in the English-speaking world, now rapidly becoming obsolete, has two fixed points; zero is taken as the temperature of a mixture of salt and ice and 100 as the temperature of the human body. This gives the freezing point of water as 32 ºF and the boiling point (at standard pressure) as 212 ºF. For a time the Met. Office used a scale of temperature called 'Absolute' which approximated to the scale now called the Kelvin. The symbol was ºA. On this scale the water froze at 273 ºA and boiled (at standard pressure) at 373 ºA. This scale may still be found on older mercury barometers and in some correction tables.

*Conversion of thermometer scales.* To convert Celsius readings to Fahrenheit use the following rule: Multiply by 9/5 and add 32. Similarly, to convert from Fahrenheit to Celsius, subtract 32 and multiply by 5/9. From Fahrenheit to kelvin (formerly known as Absolute), proceed as for Celsius and add 273.15. Table 7 gives the values on the Celsius and kelvin scales corresponding to each degree Fahrenheit, from 0 ºF. to 119 ºF.

*Scale markings.* Thermometer scales can take various forms. As the liquid-in-glass thermometer is particularly fragile, it is usually protected in some way or other, and the scale is often incorporated in this protection. In the standard Met. Office sheathed thermometer (Figure 10) the scale is engraved directly upon the thermometer stem, the back being coloured to allow easy reading. The thermometer stem is then enclosed in an outer glass tube, which adds to the strength of the whole and protects the scale from erosion. In this case the thermometer is therefore read through the outer glass tube.

Electrical thermometers are usually read by dial and pointer, the pointer either being operated by the resistance thermometer electrical circuits or by manually setting to achieve a prescribed effect - the 'zeroing' of a secondary pointer, or by the lighting or extinction of electric lamps.

*Reading the thermometer.* The thermometer should be read with care. Ships' thermometers are graduated in half degrees Celsius and the readings should be given by estimation to the nearest tenth of a degree. This is not only necessary for general accuracy but also for practical reasons, i.e. the computation of relative humidity and the dew-point, and the determination of the difference between air and sea-surface temperatures. In some coded radio weather messages, however, the temperature is required only to the nearest degree. When reading a thermometer, care should be taken to keep the eye at the same level as the end of the column, otherwise there will be an error due to parallax.

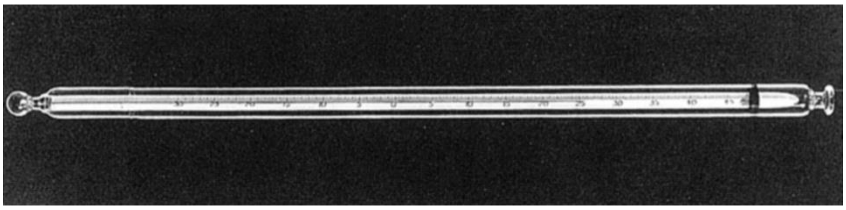

Figure 10. Air Thermometer.

The mercury column of a thermometer occasionally separates in one or more places. The thermometers should therefore be examined before each observation to see if the column is continuous. If there is any break in the column, take the instrument down, swing it briskly at arm's length with the bulb end away from you until the column is again continuous, and replace it. After this, give the thermometers another 10 minutes to pick up the correct temperatures again, before taking the observation. With the alcohol-in-glass thermometer some alcohol may flow into the upper end of the tube unless the thermometer is stored with the bulb end downwards.

Thermometers should be kept clean. In damp weather any moisture should be removed from the dry-bulb a little while before taking the reading. The graduations on the glass of mounted thermometers may in time become indistinct. Since the marks are cut in the glass, a rub with an ordinary lead pencil or wipe over with Indian ink will make the graduations clear again.

For all types of liquid-in-glass thermometer it is best always to store in a vertical or near vertical position and never with the bulb higher than the end of the stem. In consequence a spare thermometer is most conveniently retained in its box, which can be conveniently located in a rack or a clip which will hold it in a vertical position.

## THE DRY-AND WET-BULB THERMOMETERS

An instrument for measuring the humidity of the air is called a hygrometer. There are several kinds of hygrometers, but the form in common use, the dry-and wet- bulb thermometers, also known as Mason's hygrometer or a psychrometer, is the simplest and is described below.

Of the two thermometers contained in the thermometer screen, no more need be said of the dry-bulb for measuring air temperature, beyond ensuring that it is secured firmly into the clips provided. The operation of and attention to the wet- bulb thermometer requires a little further description.

*Operation of a wet-bulb thermometer.* The evaporation of water requires heat, the 'latent heat of evaporation'. This is derived from the surroundings -the air, the water itself and/or from the thermometer used for the measurement. The faster the evaporation the greater the demand for latent heat and hence the greater will be the cooling of the surroundings. However, the rate of evaporation under any particular circumstance will be determined by the dryness of the surrounding air, the air temperature and the rate at which air flows past the thermometer. A measure of humidity, i.e. the degree of dryness or wetness of the air, can thus be obtained by wetting a thermometer and noting the degree to which it is cooled. In practice it is both inconvenient and unnecessary to wet the whole thermometer -wetting the bulb alone will suffice. The bulb itself is thus enclosed in a small muslin bag, tied on by means of a wick, the other end of which is placed in a small water container placed beside the thermometer. Capillary action will then ensure that the muslin is kept wet, and the cooling action of evaporation can then be measured by reading, firstly, the dry-bulb thermometer, then the wet- bulb thermometer and by subtraction, the difference, the 'wet-bulb depression'. The third requirement is knowledge of the rate of the air flow. A value has been assumed so that, from the air temperature and wet-bulb depression, a reasonably correct measure of humidity may be obtained from the tables provided. This combination of a dry-and wet- bulb thermometer is known as a psychrometer.

Air can contain only a limited amount of evaporated water, according to its temperature. When this point is reached, no further evaporation will take place and the wet-bulb thermometer will read the same as the dry-bulb thermometer. The air is then said to be saturated. If the air becomes drier, the rate of evaporation increases and the wet-bulb temperature falls. The depression of the wet-bulb can reach over 20 ºC in a hot dry climate, such as that of Khartoum during part of the year. It sometimes amounts to 10 ºC in England, but at sea the difference seldom reaches 5 ºC. When the humidity of the atmosphere is high, during or just before or after rain, when fog is prevalent, or when dew is forming, there is little or no evaporation and the two thermometers give the same, or very nearly the same reading.

We may sum up the facts about humidity and the dry-and wet-bulb thermometers as under:

| *Humidity* | *Evaporation* | |
|---|---|---|
| High ... | Weak ... | Dry-and wet-bulbs read almost the same. |
| Low ... | Intense ... | Wet-bulb reads much lower than dry. |

*Muslin and wick for wet-bulbs.* The wet-bulb thermometer needs careful attention in order to get correct readings. The bulb of this thermometer should be covered with a single thickness of thin clean muslin or cambric, which is kept moist by attaching to it a few threads of darning cotton dipping into the small reservoir of water placed near it.

From the muslin provided, a small piece should be cut, sufficient to cover the bulb, and should be stretched smoothly over it, creases being avoided as far as possible. The muslin is kept in place by attaching the cotton wick in the following way. Take a round turn in the wick, with the strands middled on the bight, and pass the ends through the bight, forming a round turn and cow hitch. Any superfluous muslin or loose ends should then be trimmed off (Figure 11 a).

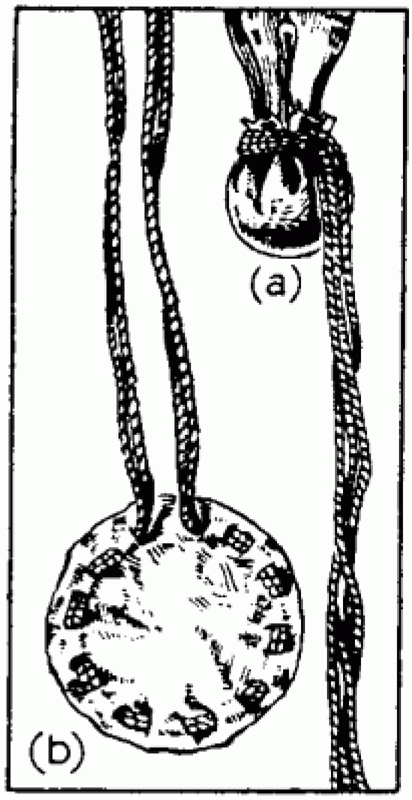


Figure 11. (a) Wet-bulb with ordinary muslin and wick, (b) Muslin cap.

Muslin caps ready threaded with cotton are usually supplied. These are slipped over the bulb, and the thread is then pulled tight and tied (Figure 11 b). The strands should be long enough to reach two or three inches below the lowest part of the bulb, in order that their lower ends can be immersed in the water vessel, but not long enough to hang in a bight, or water will drip from the wick at the lowest point of the curve until the reservoir is emptied.

*Precautions necessary in taking wet-bulb observations.* To get correct readings the muslin must be damp, but not dripping. If it is too wet, the reading of the thermometer will be too high. If it is not wet enough, the reading will again be too high. The former defect may be cured by cutting down the number of threads supplying moisture to the bulb. Take care, however, that this remedy does not make the muslin too dry.

It is important that the water should be pure. Ordinary water contains substances in solution and, if such water is used, as it evaporates it deposits these substances on the thread and muslin; the free flow of water to the muslin and its evaporation therefrom are checked, and the thermometer may read too high. Moreover, the rate of evaporation from impure water may differ appreciably from that for pure water. It is therefore desirable that distilled water should be used. This may be available from the ship's radio office, but is liable to become contaminated with acid in the course of a voyage. If, therefore, sufficient distilled water can be collected from the ship's radio office at the commencement of a voyage, this should be used. If distilled water is not available, condenser water from the engine-room may be used. Fresh water should only be used as a last resort.

The muslin should be changed at least once a week and more often if it becomes dirty or contaminated by salt spray. The presence of salt in the water will cause the thermometer to read too high and, if any spray has reached the instrument, the muslin and wick should be replaced by new ones. It is advisable to do this in any case after bad weather. If it is found that an encrustation of lime or other impurity has formed on the thermometer bulb, this should be scraped off. A note should be made in the appropriate column of the meteorological logbook whenever the muslin is changed.

After the muslin has been changed, some time must be allowed to elapse before observations are resumed. This is to ensure that the proper degree of wetting has been achieved and that the thermometer and wetted muslin have attained the properly balanced temperature.

*Wet-bulb temperature higher than dry-bulb.* If the reading of the wet-bulb thermometer is above that of the dry-bulb, first make sure that the readings were correct. Then ensure that the muslin and thread are moist but not too wet and that the dry-bulb is indeed dry. (If the latter has to be wiped, allow it to cool to the air temperature before a second reading.) If no fault is found, book the temperatures as they have been read and note in the 'Remarks' column that the reading has been checked, the muslin and thread examined, and that the ventilation is adequate.

Except as a result of a defect, it is impossible in normal circumstances for the wet-bulb to read higher than the dry if a temperature is steady, and if the wet-bulb is above freezing point (see below). If the temperature is changing, however, one of the thermometers may be more sensitive than the other and follow the temperature changes with less lag. Under such circumstances it is possible that the wet-bulb thermometer may sometimes be found to be reading higher than the dry-bulb. In such a case the wet-bulb should be taken as correct and the dry-bulb reading adjusted to equality with the wet-bulb. If this phenomenon occurs frequently and the fault cannot otherwise be traced, it may lie in one of the thermometers. These should be examined and if there is nothing obviously wrong the spare thermometer should be brought into use to replace the first one, and then (if necessary) the other thermometer, till satisfactory observations are again obtained.

*Wet-bulb readings during frost.* During frost, when the muslin is thinly coated with ice, the readings are still valid because evaporation takes place from a surface of ice as freely as from one of water. If the muslin is dry it must be given an ice coating by wetting it slightly with ice- cold water, using a camel-hair brush or by other means. The water will usually take 10 to 15 minutes to freeze. Excess of water must not be used as it takes much longer to freeze and will also not give accurate readings. After the wetting of the muslin, the temperature generally remains steady at 0 ºC until all the water has been converted to ice. It then begins to fall gradually to the true ice-bulb reading. No reading must be recorded until the temperature of the ice-bulb has fallen below that of the dry-bulb and remains steady. Dry, windy weather may cause the ice to evaporate completely before the time of the next reading, in which case the procedure of wetting the bulb must be gone through again. The original coating of ice will give satisfactory results as long as it lasts.

It must be pointed out that supercooled water may exist on the wet-bulb at temperatures well below freezing point and that, if this is not noticed by the observer, serious errors will occur. The freezing can be started by touching the wet-bulb with a snow crystal, a pencil, or other object. *Measures of humidity.* Dew-point and relative humidity can be obtained from the readings of the dry-and wet-bulb.

The dew-point is the temperature at which dew would begin to form on the bulb of the thermometer if the air were cooled down, the amount of water vapour in it remaining unchanged. Tables 4 and 5 give the dew-point for dry-bulb temperatures and depressions of the wet-bulb. The depression of the wet bulb is the difference between the dry-and wet-bulb readings. The amount of this depression depends on the ventilation to which the wet-bulb thermometer is subjected and Table 4 is to be used for observations in which the thermometers are exposed in the standard marine screen. Since the amount of evaporation from ice and water surfaces is not the same, lines are ruled in the tables to call attention to the fact that above the line evaporation is going on from a water surface while below the line it is going on from an ice surface. Intermediate figures must therefore be obtained by extrapolation.

In order that values of the wet-bulb depression of the necessary accuracy shall be available, it is especially desirable at low temperatures that the thermometers should be read to the tenth of a degree. This is because at low temperatures dew-point changes rapidly with changes in wet-bulb depression.

The relative humidity is the amount of water vapour actually present in the air, expressed as a percentage of the amount the air would contain at that temperature if it were saturated. Table 6 gives the relative humidity for dry-bulb temperature and depression of the wet-bulb. In the UK Met. Office a relative humidity of 95 per cent is taken as a guide in determining whether to report mist or haze

## ELECTRICAL RESISTANCE THERMOMETERS

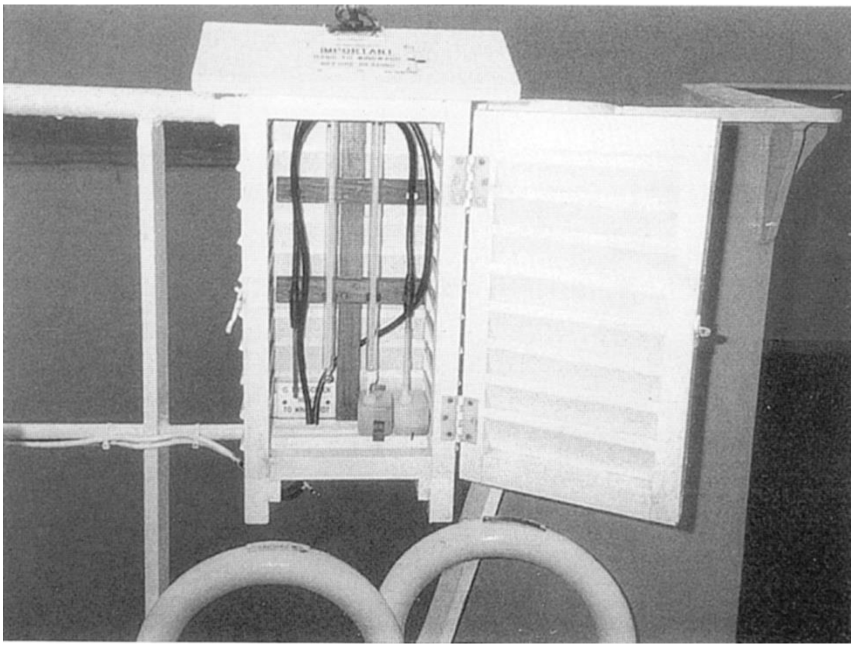

Figure 12. Marine screen with Electrical Resistance Thermometer


Figure 13. Digital Temperature Indicators. Top Mk.IB, bottom Mk.2

The electrical resistance of platinum wire varies in a known way with change of temperature. This characteristic is used in electrical resistance thermometers. Thin platinum wire in the form of a helix is enclosed inside a highly conductive ceramic former which is further enclosed in a close-fitting stainless-steel tubular sheath for protection. A plug of epoxy resin is placed in the head of the thermometer to prevent ingress of moisture to the platinum element. Electrical leads are brought through the head of the thermometer for connection to a suitable device to measure the change in resistance.

The Met. Office Resistance Thermometer Element Mk. 4A has a diameter of 4 mm and stem length of approximately 80 mm and a sensing length of 10 mm at the lower end of the stem. The thermometer is of the four-lead type.

When used as a wet-bulb thermometer a special tight-fitting tubular wick is fitted. Although the sensing part of the thermometer is located in the lower part, the wick should be placed 40 mm up the stem to ensure accurate wet-bulb reading. Sufficient loose wick should be left below the bottom of the thermometer to reach to the bottom of the water bottle. The thermometers are generally used connected to the Met. Office Digital Temperature Indicator Mk. 1B or Mk. 2 (Ships) (Figure 13).

*Digital Temperature Indicator (DTI)* The indicator is an integrated digital voltmeter, scaled in temperature, used to indicate temperature sensed by electrical resistance thermometers, which can be set up at some distance. The DTI can be used to read up to eight resistance thermometer elements. On board ship the first five push-button positions are connected to read air temperature, wet-bulb temperature from either port or starboard screens, and sea temperature from the hull sensor. When the instrument has been installed by technical staff, the operator need only press the appropriate push-button on the indicator. The display will stabilize within two seconds of selecting a channel, when the temperature will be displayed as three digits; tens, units and tenths of degrees Celsius. A negative temperature is indicated by a minus sign before the tens digit.

The DTI should always remain switched on. If the power has been switched off the instrument requires 30 minutes to warm up. A display blanking switch is situated on the left- hand side of the indicator. The equipment should be inspected by a Port Met. Officer or technician at approximately six-monthly intervals.

## THE MARINE SCREEN

*Exposure of thermometers.* No matter how accurate a thermometer may be, it can do no more than indicate its own temperature. It is therefore essential that the thermometer is in correct contact with the medium whose temperature it is to measure, in order that it may 'share' its true temperature, and that it is protected from any extraneous source of heat. When measuring the air temperature, particular problems arise on this score, in that the thermometer must be shielded from the heat radiated by the sun, the sea and from the ship itself, yet at the same time the air, which is itself transparent to such radiated heat, must be allowed to flow freely past the thermometer. Even when not in use no normal meteorological thermometer, for whatever purpose it is supplied, must ever be exposed to full sunlight for more than a moment or two, and when stored, should be kept in its packaging.

A thermometer screen is used to shield the thermometer from external radiation, yet allowing an adequate flow of air.

*Design of thermometer screen.* There are several acceptable designs of thermometer screens, although only one is regarded as the Met. Office standard marine type. The essential features of any such screen, which at present is made of wood, are that the vertical walls are composed of louvres or 'jalousies', constructed so that no direct radiation can reach the thermometers but allowing relatively free air flow to reach the thermometer, while in addition vertical ventilation is permitted through the slotted floor and through holes in an inner roof. Hence, should the air within the screen become warmer or colder than its surroundings, it may rise or sink, and be replaced by outside air of the correct temperature. Such screens are painted white as a further precaution against radiation. Screens should be repainted when necessary and a watch should be kept for possible rotting of the woodwork, particularly in the lower corners. Marine screens contain two thermometers, the dry-bulb and the wet-bulb.

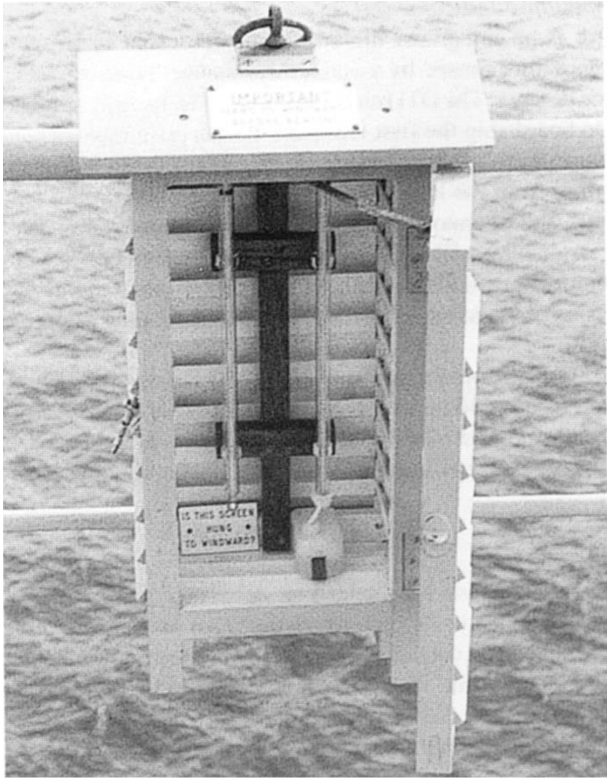

Figure 14. Marine Screen

*Position of marine screen.* The screen should be placed in the open air and, for convenience in reading the thermometers, about 1.5 metres above the deck. It may be exposed in sun or shade, attached to bridge wing rails, so as to have an unimpeded circulation of air flowing through it. It should be out of the way of unauthorized persons; it must not be exposed to suddenly varying conditions due to causes within the ship, such as draughts of air from boilers, engine-room, etc. The lighting at night should be so arranged that it cannot affect the temperature of the thermometers. By day or by night the light should come from behind or from the side of the observer.

The position of the thermometer screen requires great attention. It cannot be too strongly emphasized that the temperature of the free air is required, not of that affected by heat from the ship. The most suitable location is where the air will come direct on to the screen from the sea before passing over any part of the ship. The ship is a source of local heat; radiation takes place from the hull and from sunny decks, deck houses, etc., especially in the tropics. Radiation of heat, or warm draughts of air, may be felt from galleys, engine and boiler rooms, and funnel. The thermometer screen should be as far as possible removed from all such sources of local heating which will tend to cause false air temperatures, particularly on days when the relative wind is light. The choice of the bridge will avoid some of these sources of heating.

*Setting* up *the thermometers.* Sheathed thermometers are held in place by means of three clips. The thermometers should not be allowed to touch the floor of the screen but if they slip down through the clips a rubber grommet (obtainable from Port Met. Officers) should be placed over the thermometer, resting above the top or bottom clip. The plastic water bottle is held in place with a metal clip.

## ASPIRATED AND WHIRLING PSYCHROMETERS

The system of measuring humidity by means of dry-and wet-bulb thermometers contained in a louvred thermometer screen assumes that the design of the screen controls the internal air flow between limits usually taken as 2-4 knots. Although in the open air the assumption appears reasonably correct, there will be occasions when greater accuracy is needed or, for temporary observations, a thermometer screen cannot be erected. Moreover, the assumption will rarely, if ever, be true if temperatures and humidities are to be measured in confined spaces, for example within the hold of a ship.

The difficulty is overcome by artificially ventilating the thermometers at a controlled rate. Such thermometers are said to be 'aspirated'. Aspiration is performed by a fan which, operated by electric or clockwork motor, or even by hand (at a controlled speed) will draw air over the thermometers at a known rate. Aspirated thermometer systems include their own shield against direct radiation. An even more simple system ensures adequate ventilation by whirling or rotating the thermometers by hand at a controlled rate, the thermometers being mounted in a suitable holder to permit this. Such hand-held psychrometers are normally provided with no precautions against radiation whatsoever and must therefore be used only in the shade. This is also desirable in the case of the mechanically aspirated psychrometer.

As the rate of ventilation produced by aspirated and whirled psychrometers differs from that assumed to prevail in the static thermometer screen, different hygrometric tables must be employed, and the greatest care must be taken to ensure that the tables appropriate to the method are in fact used. Table 5, at the end of this book, is the one to be employed with aspirated and whirling psychrometers. As with Table 4, lines are ruled to draw attention to the fact that above the line evaporation is taking place from a water surface, while below the line it is occurring from an ice surface. Interpolation of readings must therefore not be made between figures on different sides of the line.

## THE APPLICATION OF HYGROMETRIC OBSERVATIONS IN THE CARE AND PROPER VENTILATION OF CARGO

Sweating, or the deposition of moisture, is a frequent cause of damage, both to cargo and to the internal structure of a ship, and it is desirable to keep a record, not only of the temperature and humidity of the outside air through which the ship is passing, but also of the temperature and humidity of the air in each hold, as far as this is practicable. Although deductions from such data will vary according to the nature of the cargo and the construction of the ship, experience of these observations should help the seaman to judge whether, at any particular time, his cargo and the structure of his ship are in danger of damage by moisture and whether conditions are likely to be improved, or the reverse, by ventilation.

**TABLE 4 — *Dew-point (°C)***
(For use with marine screen)

| Dry Bulb | Depression of Wet Bulb | | | | | | | | | | | | | | | | | | | | | | | | | Dry Bulb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | 0° | 0.2° | 0.4° | 0.6° | 0.8° | 1.0° | 1.2° | 1.4° | 1.6° | 1.8° | 2.0° | 2.5° | 3.0° | 3.5° | 4.0° | 4.5° | 5.0° | 5.5° | 6.0° | 6.5° | 7.0° | 7.5° | 8.0° | 8.5° | 9.0° | °C |
| 40 | 40 | 40 | 40 | 39 | 39 | 39 | 39 | 38 | 38 | 38 | 38 | 37 | 36 | 36 | 35 | 34 | 34 | 33 | 32 | 32 | 31 | 30 | 29 | 29 | 28 | 40 |
| 39 | 39 | 39 | 39 | 38 | 38 | 38 | 38 | 37 | 37 | 37 | 37 | 36 | 35 | 35 | 34 | 33 | 33 | 32 | 31 | 31 | 30 | 29 | 28 | 28 | 27 | 39 |
| 38 | 38 | 38 | 38 | 37 | 37 | 37 | 37 | 36 | 36 | 36 | 35 | 35 | 34 | 34 | 33 | 32 | 32 | 31 | 30 | 29 | 29 | 28 | 27 | 26 | 26 | 38 |
| 37 | 37 | 37 | 37 | 36 | 36 | 36 | 36 | 35 | 35 | 35 | 34 | 34 | 33 | 32 | 32 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 25 | 24 | 37 |
| 36 | 36 | 36 | 35 | 35 | 35 | 35 | 34 | 34 | 34 | 34 | 33 | 33 | 32 | 31 | 31 | 30 | 29 | 29 | 28 | 27 | 26 | 26 | 25 | 24 | 23 | 36 |
| 35 | 35 | 35 | 34 | 34 | 34 | 34 | 33 | 33 | 33 | 33 | 32 | 32 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 25 | 24 | 24 | 23 | 22 | 35 |
| 34 | 34 | 34 | 33 | 33 | 33 | 33 | 32 | 32 | 32 | 32 | 31 | 31 | 30 | 29 | 29 | 28 | 27 | 26 | 26 | 25 | 24 | 23 | 22 | 22 | 21 | 34 |
| 33 | 33 | 33 | 32 | 32 | 32 | 32 | 31 | 31 | 31 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 25 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 33 |
| 32 | 32 | 32 | 31 | 31 | 31 | 31 | 30 | 30 | 30 | 30 | 29 | 29 | 28 | 27 | 26 | 26 | 25 | 24 | 23 | 23 | 22 | 21 | 20 | 19 | 18 | 32 |
| 31 | 31 | 31 | 30 | 30 | 30 | 30 | 29 | 29 | 29 | 29 | 28 | 28 | 27 | 26 | 25 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 31 |
| 30 | 30 | 30 | 29 | 29 | 29 | 29 | 28 | 28 | 28 | 28 | 27 | 27 | 26 | 25 | 24 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 19 | 17 | 16 | 30 |
| 29 | 29 | 29 | 28 | 28 | 28 | 28 | 27 | 27 | 27 | 27 | 26 | 25 | 25 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 29 |
| 28 | 28 | 28 | 27 | 27 | 27 | 27 | 26 | 26 | 26 | 25 | 25 | 24 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 28 |
| 27 | 27 | 27 | 27 | 26 | 26 | 26 | 25 | 25 | 25 | 24 | 24 | 23 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 15 | 14 | 13 | 11 | 27 |
| 26 | 26 | 26 | 25 | 25 | 25 | 25 | 24 | 24 | 24 | 23 | 23 | 22 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 26 |
| 25 | 25 | 25 | 24 | 24 | 24 | 24 | 23 | 23 | 23 | 22 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 8 | 25 |
| 24 | 24 | 24 | 23 | 23 | 23 | 23 | 22 | 22 | 22 | 21 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 9 | 8 | 7 | 24 |
| 23 | 23 | 23 | 22 | 22 | 22 | 21 | 21 | 21 | 21 | 20 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 14 | 13 | 12 | 10 | 9 | 8 | 7 | 5 | 23 |
| 22 | 22 | 22 | 21 | 21 | 21 | 20 | 20 | 20 | 20 | 19 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 6 | 5 | 3 | 22 |
| 21 | 21 | 21 | 20 | 20 | 20 | 19 | 19 | 19 | 18 | 18 | 18 | 18 | 17 | 16 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 6 | 5 | 3 | 1 | 21 |
| 20 | 20 | 20 | 19 | 19 | 19 | 18 | 18 | 18 | 17 | 17 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 7 | 6 | 5 | 3 | 1 | 0 | 20 |
| 19 | 19 | 19 | 18 | 18 | 18 | 17 | 17 | 17 | 16 | 16 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 7 | 6 | 4 | 3 | 1 | 0 | −2 | 19 |
| 18 | 18 | 18 | 17 | 17 | 17 | 16 | 16 | 16 | 15 | 15 | 15 | 14 | 13 | 12 | 11 | 10 | 8 | 7 | 6 | 4 | 3 | 1 | −0 | −2 | −5 | 18 |
| 17 | 17 | 17 | 16 | 16 | 16 | 15 | 15 | 15 | 14 | 14 | 14 | 13 | 12 | 11 | 9 | 8 | 7 | 6 | 4 | 3 | 1 | −0 | −3 | −5 | −7 | 17 |
| 16 | 16 | 16 | 15 | 15 | 15 | 14 | 14 | 14 | 13 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 4 | 3 | 1 | 0 | −2 | −5 | −7 | −10 | 16 |
| 15 | 15 | 15 | 14 | 14 | 14 | 13 | 13 | 12 | 12 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 4 | 3 | 1 | 0 | −2 | −5 | −7 | −10 | −14 | 15 |
| 14 | 14 | 14 | 13 | 13 | 13 | 12 | 12 | 11 | 11 | 11 | 10 | 9 | 8 | 7 | 6 | 4 | 3 | 1 | 0 | −2 | −4 | −7 | −10 | −13 | −18 | 14 |
| 13 | 13 | 13 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 9 | 9 | 8 | 7 | 6 | 4 | 3 | 1 | 0 | −2 | −4 | −7 | −9 | −13 | −17 | −23 | 13 |
| 12 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 | 9 | 8 | 8 | 7 | 6 | 4 | 3 | 1 | 0 | −2 | −4 | −6 | −9 | −12 | −16 | −22 | −33 | 12 |
| 11 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 7 | 7 | 6 | 4 | 3 | 1 | 0 | −2 | −4 | −6 | −8 | −12 | −15 | −21 | −30 | | 11 |
| 10 | 10 | 10 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 6 | 6 | 4 | 3 | 2 | 0 | −2 | -3 | −6 | −8 | 11 | 15 | −19 | −27 | | | 10 |

**TABLE 4 — *(contd)***

| Dry Bulb °C | 0° | 0.2° | 0.4° | 0.6° | 0.8° | 1.0° | 1.2° | 1.4° | 1.6° | 1.8° | 2.0° | 2.5° | 3.0° | 3.5° | 4.0° | 4.5° | 5.0° | 5.5° | 6.0° | 6.5° | 7.0° | Dry Bulb °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depression of Wet Bulb | | | | | | | | | | | | | | | | | | | | | |
| 9 | 9 | 9 | 8 | 8 | 7 | 7 | 6 | 6 | 5 | 5 | 4 | 3 | 2 | 0 | −1 | −3 | −5 | −8 | −10 | −14 | −18 | 9 |
| 8 | 8 | 8 | 7 | 7 | 6 | 6 | 5 | 5 | 4 | 4 | 3 | 2 | 0 | −1 | −3 | −5 | −7 | −10 | −13 | −17 | | 8 |
| 7 | 7 | 7 | 6 | 6 | 5 | 5 | 4 | 4 | 3 | 3 | 2 | 1 | −1 | −3 | −4 | −7 | −9 | −12 | −16 | | | 7 |
| 6 | 6 | 6 | 5 | 5 | 4 | 4 | 3 | 3 | 2 | 1 | 1 | −0 | −2 | −4 | −6 | −9 | −11 | −15 | | | | 6 |
| 5 | 5 | 5 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | −2 | −4 | −6 | −8 | −10 | −14 | −15 | | | | 5 |
| 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | −1 | −1 | −3 | −5 | −7 | −10 | −11 | −14 | −18 | | | | 4 |
| 3 | 3 | 3 | 2 | 1 | 1 | 0 | 0 | −1 | −2 | −2 | −3 | −5 | −7 | −8 | −11 | −14 | −17 | | | | | 3 |
| 2 | 2 | 2 | 1 | 0 | 0 | −1 | −1 | −2 | −3 | −3 | −4 | −5 | −8 | −10 | −13 | −16 | | | | | | 2 |
| 1 | 1 | 1 | 0 | −1 | −1 | −2 | −2 | −3 | −4 | −4 | −5 | −7 | −9 | −12 | −15 | −19 | | | | | | 1 |
| 0 | 0 | −1 | −1 | −2 | −2 | −3 | −4 | −4 | −5 | −6 | −7 | −9 | −11 | −14 | −18 | | | | | | | 0 |
| −1 | −1 | −2 | −2 | −3 | −4 | −4 | −5 | −6 | −6 | −7 | −8 | −10 | −13 | −17 | | | | | | | | |
| −2 | −2 | −3 | −4 | −4 | −5 | −6 | −6 | −7 | −8 | −9 | −10 | −12 | −15 | −19 | | | | | | | | |
| −3 | −3 | −4 | −5 | −5 | −6 | −7 | −8 | −9 | −9 | −10 | −11 | −14 | −18 | | | | | | | | | |
| −4 | −5 | −5 | −6 | −7 | −7 | −8 | −9 | −10 | −11 | −12 | −13 | −16 | | | | | | | | | | |
| −5 | −6 | −6 | −7 | −8 | −9 | −10 | −10 | −11 | −13 | −14 | −15 | −18 | | | | | | | | | | |
| −6 | −7 | −7 | −8 | −9 | −10 | −11 | −12 | −13 | −14 | −15 | −17 | | | | | | | | | | | |
| −7 | −8 | −9 | −9 | −10 | −11 | −12 | −13 | −15 | −16 | −17 | −19 | | | | | | | | | | | |
| −8 | −9 | −10 | −11 | −12 | −13 | −14 | −15 | −16 | −18 | −19 | | | | | | | | | | | | |
| −9 | −10 | −11 | −12 | −13 | −14 | −15 | −17 | −18 | −19 | | | | | | | | | | | | | |
| −10 | −11 | −12 | −13 | −14 | −15 | −17 | −18 | | | | | | | | | | | | | | | |
| −11 | −12 | −13 | −14 | −16 | −17 | −18 | | | | | | | | | | | | | | | | |
| −12 | −13 | −14 | −16 | −17 | −18 | | | | | | | | | | | | | | | | | |
| −13 | −15 | −16 | −17 | −18 | | | | | | | | | | | | | | | | | | |
| −14 | −16 | −17 | −18 | | | | | | | | | | | | | | | | | | | |
| −15 | −17 | −18 | −19 | | | | | | | | | | | | | | | | | | | |
| −16 | −18 | −19 | | | | | | | | | | | | | | | | | | | | |
| −17 | −19 | | | | | | | | | | | | | | | | | | | | | |

In the tables, lines are ruled to draw attention to the fact that above the line evaporation is going on from a water surface, while below the line it is going on from an ice surface. Owing to this, interpolation must not be made between figures on different sides of the lines.

For dry bulb temperatures below 0°C it will be noticed that, when the depression of the wet bulb is zero, i.e. when the temperature of the wet bulb is equal to that of the dry bulb, the dew-point is still below the dry bulb, and the relative humidity is less than 100 per cent. These apparent anomalies are a consequence of the method of computing dew-points and relative humidities now adopted by the Met. Office, in which the standard saturation pressure for temperatures below 0°C is taken as that over water, and not as that over ice.

**TABLE 5 — *Dew-point (°C)***

(For use with aspirated psychrometer)

| Dry Bulb °C | 0° | 0.5° | 1.0° | 1.5° | 2.0° | 2.5° | 3.0° | 3.5° | 4.0° | 4.5° | 5.0° | 5.5° | 6.0° | 6.5° | 7.0° | 7.5° | 8.0° | 8.5° | 9.0° | Dry Bulb °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depression of Wet Bulb | | | | | | | | | | | | | | | | | | | |
| 40 | 40 | 39 | 39 | 38 | 38 | 37 | 36 | 36 | 35 | 35 | 34 | 33 | 33 | 32 | 31 | 31 | 30 | 29 | 29 | 40 |
| 39 | 39 | 38 | 38 | 37 | 37 | 36 | 35 | 35 | 34 | 33 | 33 | 32 | 32 | 31 | 30 | 29 | 29 | 28 | 27 | 39 |
| 38 | 38 | 37 | 37 | 36 | 36 | 35 | 34 | 34 | 33 | 32 | 32 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 38 |
| 37 | 37 | 36 | 36 | 35 | 35 | 34 | 33 | 33 | 32 | 31 | 31 | 30 | 29 | 29 | 28 | 27 | 27 | 26 | 25 | 37 |
| 36 | 36 | 35 | 35 | 34 | 34 | 33 | 32 | 32 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 25 | 25 | 24 | 36 |
| 35 | 35 | 34 | 34 | 33 | 33 | 32 | 31 | 31 | 30 | 29 | 29 | 28 | 27 | 26 | 26 | 25 | 24 | 24 | 23 | 35 |
| 34 | 34 | 33 | 33 | 32 | 31 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 25 | 25 | 24 | 23 | 22 | 22 | 34 |
| 33 | 33 | 32 | 32 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 26 | 25 | 24 | 23 | 23 | 22 | 21 | 20 | 33 |
| 32 | 32 | 31 | 31 | 30 | 29 | 29 | 28 | 27 | 27 | 26 | 25 | 25 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 32 |
| 31 | 31 | 30 | 30 | 29 | 28 | 28 | 27 | 26 | 26 | 25 | 24 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 31 |
| 30 | 30 | 29 | 29 | 28 | 27 | 27 | 26 | 25 | 25 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 18 | 17 | 17 | 30 |
| 29 | 29 | 28 | 28 | 27 | 26 | 26 | 25 | 24 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 16 | 15 | 29 |
| 28 | 28 | 27 | 27 | 26 | 25 | 25 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 15 | 14 | 28 |
| 27 | 27 | 26 | 26 | 25 | 24 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 16 | 16 | 15 | 14 | 13 | 27 |
| 26 | 26 | 25 | 25 | 24 | 23 | 23 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 26 |
| 25 | 25 | 24 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 25 |
| 24 | 24 | 23 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 16 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 8 | 24 |
| 23 | 23 | 22 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 23 |
| 22 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 5 | 22 |
| 21 | 21 | 20 | 20 | 19 | 18 | 17 | 16 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 6 | 5 | 4 | 21 |
| 20 | 20 | 19 | 19 | 18 | 17 | 16 | 15 | 14 | 14 | 13 | 12 | 11 | 10 | 9 | 7 | 6 | 5 | 4 | 2 | 20 |
| 19 | 19 | 18 | 17 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 3 | 2 | 0 | 19 |
| 18 | 18 | 17 | 16 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 3 | 2 | 0 | −1 | 18 |
| 17 | 17 | 16 | 15 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 4 | 3 | 2 | 0 | −2 | −3 | 17 |
| 16 | 16 | 15 | 14 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 5 | 4 | 3 | 2 | 0 | −2 | −4 | −6 | 16 |
| 15 | 15 | 14 | 13 | 12 | 12 | 11 | 10 | 9 | 8 | 7 | 5 | 4 | 3 | 1 | 0 | −2 | −4 | −6 | −8 | 15 |
| 14 | 14 | 13 | 12 | 11 | 10 | 10 | 9 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −2 | −4 | −6 | −8 | −11 | 14 |
| 13 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −2 | −4 | −6 | −8 | −11 | −14 | 13 |
| 12 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −2 | −4 | −6 | −8 | −10 | −13 | −17 | 12 |
| 11 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −2 | −3 | −5 | −8 | −10 | −13 | −17 | −22 | 11 |
| 10 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −2 | −3 | −5 | −7 | −10 | −13 | −16 | −21 | −29 | 10 |

**TABLE 5 — *(contd)***

| Dry Bulb | Depression of Wet Bulb | | | | | | | | | | | | | | | | | | | Dry Bulb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | 0° | 0.5° | 1.0° | 1.5° | 2.0° | 2.5° | 3.0° | 3.5° | 4.0° | 4.5° | 5.0° | 5.5° | 6.0° | 6.5° | 7.0° | 7.5° | 8.0° | 8.5° | 9.0° | °C |
| 9 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −2 | −3 | −5 | −7 | −9 | −12 | −16 | −20 | −27 | −45 | 9 |
| 8 | 8 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −2 | −3 | −5 | −7 | −9 | −12 | −15 | −19 | −25 | −25 | −36 | 8 |
| 7 | 7 | 6 | 5 | 4 | 3 | 1 | 0 | −1 | −3 | −5 | −7 | −9 | −11 | −14 | −18 | −19 | −24 | −34 | | 7 |
| 6 | 6 | 5 | 4 | 3 | 1 | 0 | −1 | −3 | −4 | −6 | −8 | −11 | −14 | −14 | −18 | −23 | −32 | | | 6 |
| 5 | 5 | 4 | 3 | 2 | 0 | −1 | −3 | −4 | −6 | −8 | −10 | −11 | −14 | −18 | −22 | −30 | | | | 5 |
| 4 | 4 | 3 | 2 | 0 | −1 | −2 | −4 | −6 | −8 | −9 | −11 | −14 | −17 | −22 | −28 | −45 | | | | 4 |
| 3 | 3 | 2 | 1 | −1 | −2 | −4 | −5 | −6 | −8 | −11 | −13 | −16 | −21 | −27 | −39 | | | | | 3 |
| 2 | 2 | 1 | 0 | −2 | −3 | −4 | −6 | −8 | −10 | −13 | −16 | −20 | −25 | −34 | | | | | | 2 |
| 1 | 1 | 0 | −2 | −3 | −4 | −6 | −8 | −10 | −12 | −15 | −19 | −24 | −31 | | | | | | | 1 |
| 0 | 0 | −1 | −3 | −4 | −6 | −8 | −9 | −12 | −14 | −18 | −22 | −29 | −44 | | | | | | | 0 |
| −1 | −1 | −2 | −4 | −5 | −7 | −9 | −11 | −14 | −17 | −21 | −26 | −37 | | | | | | | | |
| −2 | −2 | −4 | −5 | −7 | −9 | −11 | −13 | −16 | −19 | −24 | −32 | | | | | | | | | |
| −3 | −3 | −5 | −6 | −8 | −10 | −12 | −15 | −18 | −23 | −29 | −44 | | | | | | | | | |
| −4 | −4 | −6 | −8 | −10 | −12 | −14 | −17 | −21 | −26 | −36 | | | | | | | | | | |
| −5 | −5 | −7 | −9 | −11 | −13 | −16 | −19 | −24 | −31 | | | | | | | | | | | |
| −6 | −6 | −8 | −10 | −13 | −15 | −18 | −22 | −28 | −39 | | | | | | | | | | | |
| −7 | −7 | −10 | −12 | −14 | −17 | −20 | −25 | −32 | | | | | | | | | | | | |
| −8 | −8 | −11 | −13 | −16 | −19 | −23 | −28 | −40 | | | | | | | | | | | | |
| −9 | −9 | −12 | −14 | −17 | −21 | −25 | −33 | | | | | | | | | | | | | |
| −10 | −10 | −13 | −16 | −19 | −23 | −28 | −39 | | | | | | | | | | | | | |
| −11 | −11 | −15 | −17 | −21 | −25 | −32 | | | | | | | | | | | | | | |
| −12 | −12 | −16 | −19 | −23 | −28 | −38 | | | | | | | | | | | | | | |
| −13 | −13 | −17 | −20 | −25 | −31 | −47 | | | | | | | | | | | | | | |
| −14 | −14 | −18 | −22 | −27 | −35 | | | | | | | | | | | | | | | |
| −15 | −15 | −20 | −24 | −29 | −40 | | | | | | | | | | | | | | | |
| −16 | −16 | −21 | −25 | −32 | | | | | | | | | | | | | | | | |
| −17 | −17 | −22 | −27 | −35 | | | | | | | | | | | | | | | | |

See footnotes to Table 4

**TABLE 6 — *Relative Humidity (per cent)***

(For use with marine screen)

| Dry Bulb | Depression of Wet Bulb | | | | | | | | | | | | | | | | | | | | | | | Dry Bulb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | 0.2° | 0.4° | 0.6° | 0.8° | 1.0° | 1.2° | 1.4° | 1.6° | 1.8° | 2.0° | 2.5° | 3.0° | 3.5° | 4.0° | 4.5° | 5.0° | 5.5° | 6.0° | 6.5° | 7.0° | 7.5° | 8.0° | 8.5° | 9.0° | °C |
| 40 | 99 | 97 | 96 | 95 | 94 | 92 | 91 | 90 | 89 | 88 | 85 | 82 | 79 | 76 | 73 | 71 | 68 | 66 | 63 | 61 | 58 | 56 | 53 | 51 | 40 |
| 39 | 99 | 97 | 96 | 95 | 94 | 92 | 91 | 90 | 89 | 87 | 84 | 82 | 79 | 76 | 73 | 70 | 68 | 65 | 63 | 60 | 58 | 55 | 53 | 50 | 39 |
| 38 | 99 | 97 | 96 | 95 | 94 | 92 | 91 | 90 | 89 | 87 | 84 | 81 | 78 | 75 | 73 | 70 | 67 | 65 | 62 | 59 | 57 | 54 | 52 | 50 | 38 |
| 37 | 99 | 97 | 96 | 95 | 93 | 92 | 91 | 90 | 88 | 87 | 84 | 81 | 78 | 75 | 72 | 69 | 67 | 64 | 61 | 59 | 56 | 54 | 51 | 49 | 37 |
| 36 | 99 | 97 | 96 | 95 | 93 | 92 | 91 | 90 | 88 | 87 | 84 | 81 | 78 | 75 | 72 | 69 | 66 | 63 | 61 | 58 | 55 | 53 | 50 | 48 | 36 |
| 35 | 99 | 97 | 96 | 95 | 93 | 92 | 91 | 89 | 88 | 87 | 83 | 80 | 77 | 74 | 71 | 68 | 65 | 63 | 60 | 57 | 55 | 52 | 49 | 47 | 35 |
| 34 | 99 | 97 | 96 | 95 | 93 | 92 | 91 | 89 | 88 | 86 | 83 | 80 | 77 | 74 | 71 | 68 | 65 | 62 | 59 | 56 | 54 | 51 | 49 | 46 | 34 |
| 33 | 99 | 97 | 96 | 94 | 93 | 91 | 90 | 89 | 87 | 86 | 83 | 80 | 76 | 73 | 70 | 67 | 64 | 61 | 58 | 56 | 53 | 50 | 48 | 45 | 33 |
| 32 | 99 | 97 | 96 | 94 | 93 | 91 | 90 | 89 | 87 | 86 | 83 | 79 | 76 | 73 | 70 | 67 | 64 | 61 | 58 | 55 | 52 | 49 | 47 | 44 | 32 |
| 31 | 99 | 97 | 96 | 94 | 93 | 91 | 90 | 88 | 87 | 86 | 82 | 79 | 75 | 72 | 69 | 66 | 63 | 60 | 57 | 54 | 51 | 48 | 46 | 43 | 31 |
| 30 | 98 | 97 | 95 | 94 | 93 | 91 | 90 | 88 | 87 | 85 | 82 | 78 | 75 | 72 | 68 | 65 | 62 | 59 | 56 | 53 | 50 | 47 | 44 | 42 | 30 |
| 29 | 98 | 97 | 95 | 94 | 92 | 91 | 89 | 88 | 86 | 85 | 81 | 78 | 74 | 71 | 68 | 65 | 61 | 58 | 55 | 52 | 49 | 46 | 43 | 40 | 29 |
| 28 | 98 | 97 | 95 | 94 | 92 | 91 | 89 | 88 | 86 | 85 | 81 | 77 | 74 | 70 | 67 | 64 | 60 | 57 | 54 | 51 | 48 | 45 | 42 | 39 | 28 |
| 27 | 98 | 97 | 95 | 94 | 92 | 90 | 89 | 87 | 86 | 84 | 81 | 77 | 73 | 70 | 66 | 63 | 60 | 56 | 53 | 50 | 47 | 44 | 41 | 38 | 27 |
| 26 | 98 | 97 | 95 | 93 | 92 | 90 | 89 | 87 | 86 | 84 | 80 | 76 | 73 | 69 | 66 | 62 | 59 | 55 | 52 | 49 | 46 | 42 | 39 | 36 | 26 |
| 25 | 98 | 97 | 95 | 93 | 92 | 90 | 88 | 87 | 85 | 84 | 80 | 76 | 72 | 68 | 65 | 61 | 58 | 54 | 51 | 47 | 44 | 41 | 38 | 35 | 25 |
| 24 | 98 | 97 | 95 | 93 | 91 | 90 | 88 | 86 | 85 | 83 | 79 | 75 | 71 | 68 | 64 | 60 | 57 | 53 | 50 | 46 | 43 | 39 | 36 | 33 | 24 |
| 23 | 98 | 96 | 95 | 93 | 91 | 90 | 88 | 86 | 84 | 83 | 79 | 75 | 71 | 67 | 63 | 59 | 56 | 52 | 48 | 45 | 41 | 38 | 35 | 31 | 23 |
| 22 | 98 | 96 | 95 | 93 | 91 | 89 | 88 | 86 | 84 | 82 | 78 | 74 | 70 | 66 | 62 | 58 | 54 | 51 | 47 | 43 | 40 | 36 | 33 | 29 | 22 |
| 21 | 98 | 96 | 94 | 93 | 91 | 89 | 87 | 85 | 84 | 82 | 78 | 73 | 69 | 65 | 61 | 57 | 53 | 49 | 45 | 42 | 38 | 34 | 31 | 27 | 21 |
| 20 | 98 | 96 | 94 | 92 | 91 | 89 | 87 | 85 | 83 | 81 | 77 | 73 | 68 | 64 | 60 | 56 | 52 | 48 | 44 | 40 | 36 | 33 | 29 | 25 | 20 |
| 19 | 98 | 96 | 94 | 92 | 90 | 88 | 86 | 85 | 83 | 81 | 76 | 72 | 67 | 63 | 59 | 55 | 50 | 46 | 42 | 38 | 34 | 31 | 27 | 23 | 19 |
| 18 | 98 | 96 | 94 | 92 | 90 | 88 | 86 | 84 | 82 | 80 | 76 | 71 | 66 | 62 | 58 | 53 | 49 | 45 | 41 | 36 | 32 | 28 | 25 | 21 | 18 |
| 17 | 98 | 96 | 94 | 92 | 90 | 88 | 86 | 84 | 82 | 80 | 75 | 70 | 65 | 61 | 56 | 52 | 47 | 43 | 39 | 34 | 30 | 26 | 22 | 18 | 17 |
| 16 | 98 | 96 | 94 | 91 | 89 | 87 | 85 | 83 | 81 | 79 | 74 | 69 | 64 | 60 | 55 | 50 | 46 | 41 | 37 | 32 | 28 | 24 | 20 | 16 | 16 |
| 15 | 98 | 96 | 93 | 91 | 89 | 87 | 85 | 83 | 81 | 78 | 73 | 68 | 63 | 58 | 53 | 49 | 44 | 39 | 35 | 30 | 26 | 21 | 17 | 13 | 15 |
| 14 | 98 | 95 | 93 | 91 | 89 | 86 | 84 | 82 | 80 | 78 | 72 | 67 | 62 | 57 | 52 | 47 | 42 | 37 | 32 | 28 | 23 | 18 | 14 | 10 | 14 |
| 13 | 98 | 95 | 93 | 91 | 88 | 86 | 84 | 81 | 79 | 77 | 71 | 66 | 61 | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 16 | 11 | 6 | 13 |
| 12 | 98 | 95 | 93 | 90 | 88 | 86 | 83 | 81 | 78 | 76 | 70 | 65 | 59 | 54 | 48 | 43 | 38 | 32 | 27 | 22 | 17 | 12 | 8 | 3 | 12 |
| 11 | 97 | 95 | 92 | 90 | 87 | 85 | 83 | 80 | 78 | 75 | 69 | 63 | 58 | 52 | 46 | 41 | 35 | 30 | 25 | 19 | 14 | 9 | 4 | | 11 |
| 10 | 97 | 95 | 92 | 90 | 87 | 84 | 82 | 79 | 77 | 74 | 68 | 62 | 56 | 50 | 44 | 38 | 33 | 27 | 22 | 16 | 11 | 5 | | | 10 |

**TABLE 6 — *(contd)***

| Dry Bulb | Depression of Wet Bulb | | | | | | | | | | | | | | | | | | | | | | Dry Bulb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | 0.2° | 0.4° | 0.6° | 0.8° | 1.0° | 1.2° | 1.4° | 1.6° | 1.8° | 2.0° | 2.5° | 3.0° | 3.5° | 4.0° | 4.5° | 5.0° | 5.5° | 6.0° | 6.5° | 7.0° | 7.5° | 8.0° | °C |
| 9 | 97 | 95 | 92 | 89 | 86 | 84 | 81 | 79 | 76 | 73 | 67 | 61 | 54 | 48 | 42 | 36 | 30 | 24 | 18 | 13 | 7 | 2 | 9 |
| 8 | 97 | 94 | 92 | 89 | 86 | 83 | 80 | 78 | 75 | 72 | 66 | 59 | 52 | 46 | 40 | 33 | 27 | 21 | 15 | 9 | 3 | | 8 |
| 7 | 97 | 94 | 91 | 88 | 85 | 82 | 80 | 77 | 74 | 71 | 64 | 57 | 50 | 44 | 37 | 31 | 24 | 18 | 11 | 5 | 5 | | 7 |
| 6 | 97 | 94 | 91 | 88 | 85 | 82 | 79 | 76 | 73 | 70 | 63 | 55 | 48 | 41 | 34 | 28 | 21 | 14 | 13 | 6 | | | 6 |
| 5 | 97 | 94 | 90 | 87 | 84 | 81 | 78 | 75 | 72 | 69 | 61 | 53 | 46 | 39 | 31 | 24 | 22 | 15 | 8 | 2 | | | 5 |
| 4 | 97 | 93 | 90 | 87 | 83 | 80 | 77 | 74 | 70 | 67 | 59 | 51 | 44 | 36 | 32 | 25 | 18 | 10 | 3 | | | | 4 |
| 3 | 96 | 93 | 89 | 86 | 83 | 79 | 76 | 72 | 69 | 66 | 57 | 49 | 44 | 36 | 28 | 21 | 14 | 6 | | | | | 3 |
| 2 | 96 | 93 | 89 | 85 | 82 | 78 | 75 | 71 | 67 | 64 | 58 | 49 | 41 | 33 | 24 | 16 | 9 | 1 | | | | | 2 |
| 1 | 96 | 92 | 88 | 85 | 81 | 78 | 75 | 71 | 67 | 64 | 55 | 46 | 37 | 29 | 20 | 12 | 3 | | | | | | 1 |
| 0 | 96 | 92 | 88 | 84 | 80 | 76 | 73 | 69 | 65 | 61 | 52 | 43 | 33 | 24 | 16 | 7 | | | | | | | 0 |
| −1 | 95 | 91 | 87 | 83 | 78 | 74 | 70 | 66 | 62 | 58 | 49 | 39 | 29 | 20 | 11 | 1 | | | | | | | −1 |
| −2 | 94 | 89 | 85 | 81 | 77 | 72 | 68 | 64 | 60 | 56 | 45 | 35 | 25 | 15 | 5 | | | | | | | | −2 |
| −3 | 93 | 88 | 84 | 79 | 75 | 70 | 66 | 61 | 57 | 53 | 42 | 31 | 21 | 10 | | | | | | | | | −3 |
| −4 | 91 | 87 | 82 | 77 | 72 | 68 | 63 | 59 | 54 | 49 | 38 | 27 | 16 | 5 | | | | | | | | | −4 |
| −5 | 90 | 85 | 80 | 75 | 70 | 65 | 61 | 56 | 51 | 46 | 34 | 22 | 11 | | | | | | | | | | −5 |
| −6 | 89 | 84 | 79 | 73 | 68 | 63 | 58 | 53 | 48 | 42 | 30 | 17 | 5 | | | | | | | | | | −6 |
| −7 | 88 | 82 | 77 | 71 | 66 | 60 | 55 | 49 | 44 | 39 | 25 | 12 | | | | | | | | | | | −7 |
| −8 | 87 | 81 | 75 | 69 | 63 | 57 | 52 | 46 | 40 | 35 | 20 | 6 | | | | | | | | | | | −8 |
| −9 | 85 | 79 | 73 | 67 | 61 | 54 | 48 | 42 | 36 | 30 | 15 | | | | | | | | | | | | −9 |
| −10 | 84 | 77 | 71 | 64 | 58 | 51 | 45 | 38 | 32 | 26 | | | | | | | | | | | | | |
| −11 | 83 | 76 | 69 | 62 | 55 | 48 | 41 | 34 | 27 | 21 | | | | | | | | | | | | | |
| −12 | 81 | 74 | 67 | 59 | 52 | 44 | 37 | 30 | 22 | 15 | | | | | | | | | | | | | |
| −13 | 80 | 72 | 64 | 56 | 48 | 41 | 33 | 25 | 17 | 9 | | | | | | | | | | | | | |
| −14 | 79 | 70 | 62 | 53 | 45 | 36 | 28 | 20 | 11 | 3 | | | | | | | | | | | | | |
| −15 | 77 | 68 | 59 | 50 | 41 | 32 | 23 | 14 | 5 | | | | | | | | | | | | | | |
| −16 | 76 | 66 | 56 | 47 | 37 | 27 | 18 | 8 | | | | | | | | | | | | | | | |
| −17 | 74 | 64 | 53 | 43 | 33 | 22 | 12 | 2 | | | | | | | | | | | | | | | |

In the tables, lines are ruled to draw attention to the fact that above the line evaporation is going on from a water surface, while below the line it is going on from an ice surface (wet-bulb temperature 0°C). Owing to this, interpolation must not be made between figures on different sides of the line.

**Sea temperature**

SEA TEMPERATURE

The routine meteorological requirement is for observation of sea-water tempera-ture taken from near or just below the surface. The precise depth is not specified but any one of several methods is regarded as adequate. These methods are:

1. (a) by obtaining a sample by bucket;
2. (b) by thermometer immersed in the sea or in proximity to the sea;
3. (c) by engine-room intake temperature;
4. (d) by Met. Office supplied electronic distant reading equipment with hull- mounted sea sensor;
5. (e) by Expendable Bathythermograph (XBT).

*Bucket method*

From a slow-moving ship having a bridge height of up to about 10 metres it is comparatively easy to draw a sample of sea water on board by almost any form of bucket strong enough to withstand the water pressure while being towed. A thermometer may then be inserted and the water temperature measured. Small buckets made of double-skinned canvas or rubber are very suitable for this pur-pose. Single-skinned canvas buckets are not suitable because any evaporation from the sides of the bucket would lower the temperature of the water sample.

The problem of obtaining a sea-water sample with a bucket becomes increasingly difficult as ships' size, speed and height of bridge are increased. Canvas buckets are so light that they would obviously be unsuitable for a fast ship from a high bridge. Even if not torn away on entry into the sea, little water would remain by the time it had been drawn up to deck level and the bucket's life would be very short. A smaller and somewhat heavier bucket made of rubber reinforced by canvas is now supplied to all UK Voluntary Observing Ships. This bucket is little more than a closed length of rubber hose and it is suitable for taking sea temperatures in almost any ship, but a complete solution of successfully using a bucket regardless of the size and speed of ship has yet to be found. Extensive trials with this rubber bucket have shown that the temperature of the water sample changes very slowly after it has been hove on deck.

The small rubber buckets described above were originally designed to contain a thermometer which was lowered and immersed in the sea with the bucket itself. A high rate of thermometer breakage was experienced and the policy now is to immerse the thermometer in its sheath into the sample of sea water when the bucket is drawn up on deck. There is in fact little disadvantage in this: whether the thermometer is immersed in the sea or inserted later, it will do no more than measure the temperature of the sample at the moment of observing.

Whichever type of bucket is used, it should be swung as far out as possible to avoid the shallow layers of water close to the hull which have been warmed by the ship itself. Probably the best way of getting the water sample is to use the bucket as though one were taking a cast of the hand lead. On entering the water the buck-et should submerge quickly and cleanly. If drawn along the surface, a fault to which some designs are particularly prone, it will be filled with spray, possessing some temperature intermediate to that of the sea and that of the air.


Figure 15. Sea temperature bucket and thermometer.

On being withdrawn, a thermometer should be inserted into the sample immediately. This should be done in the shade; direct sunlight, in addition to its direct effect upon the thermometer, can warm the sea-water sample very quickly.

Individual thermometers are calibrated either for complete immersion into the medium whose temperature is to be measured, or for contact through the thermometer bulb alone (e.g. clinical thermometers). Meteorological thermometers are invariably of the former class and, if not large, would give rise to unacceptable errors when the air/sea temperature differences are large. In consequence the whole thermometer should be covered by the sea water without touching either the sides or bottom of the bucket. Devices which hold the thermometer within the bucket may be available, but otherwise it should be held at the extreme end by finger tip, without actually letting the fingers (which are a source of heat) enter the sample.

With the large canvas bucket the thermometer should be moved with a slow stirring action. After immersion for about one minute the thermometer should be withdrawn just sufficiently to allow the scale to be read, the bulb and as much of the stem as possible being left immersed. The special sea-temperature thermometer, when supplied, should be used for this purpose, but almost any meteorological thermometer may be used, including those employed for wet- and dry-bulb observations. After use, the thermometer should be dried and returned to its box for storage with the bulb end downwards.

*Distant-reading thermometers*

There would obviously be many advantages in measuring temperature by means of a distant- reading instrument while the thermometer bulb was actually immersed in the sea. In its most simple form such a device would be lowered by cable alongside the ship and readings taken inboard while it was towed. There are, however, certain difficulties in such a method. It is difficult to control the depth of such a device or even ensure that it enters the water at all and does not merely skip along the surface. The strain of towing upon the cable can also be a cause of error in the electrical measurements, while a freely towed device could damage itself against the side of the ship.

The system evolved by the Met. Office and installed in new buildings and modem ships places the thermometer inside the hull, measuring the sea temperature by conduction through the ship's side plating, the principle being that steel is such a good conductor that it transmits the temperature of the surrounding sea water. The

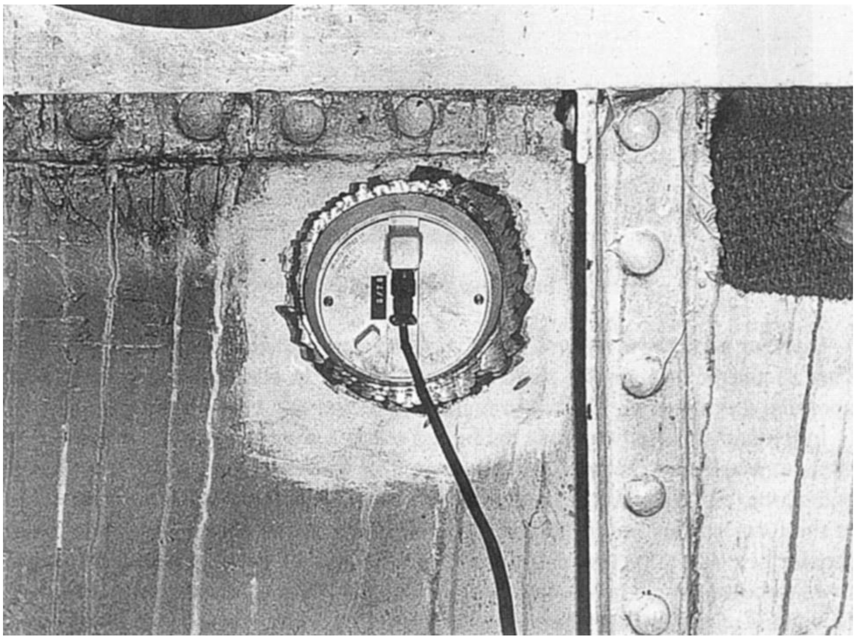

Figure 16. Distant-reading sea temperature plate

thermometer, which is in the form of a small, thin, printed electrical resistance circuit little bigger than a postage stamp, is fixed to the inside of the hull of the ship at a point a metre or so below the normal water-line. The system which requires the whole plate to change temperature with that of the sea, has a long time lag, and is thus unaffected by short-period roll or pitch, but would be invalidated if the position of the thermometer were raised above sea level by change in loading. The system demands cabling to the place where temperatures are to be read, normally the bridge, and installation is best carried out during the construction of the ship.

*Engine-room intake temperatures*

The temperature of the engine-room intake water can be taken as a measure of seawater temperature either by thermometer or by thermograph. To an extent dependent on the individual ship, the accuracy will be questionable although the method is very convenient and may well be the only one possible (in the absence of the hull thermometer described above) when the bucket method cannot be used because of rough seas, too great a ship speed or a bridge too high above the water. The errors arise from the varying depth from which the water is drawn as the ship rolls or pitches and the risk of pre-heating as the water passes through pipes at or close to engine-room temperature or through oil and water tanks on the inside of the hull. A sample of the intake water may be drawn off by tap, the subsequent procedure being that described in the bucket method above, or the temperature measured by a thermometer installed within the intake pipe. In the latter case the thermometer will usually be inserted in a pocket formed within the pipe, and the main problem which then arises is of assuring good thermal conductivity. Digital readings of sea temperature in the engine control room can be relayed by telephone or electronic means to the bridge.

## BATHYTHERMOGRAPH

This is an instrument used on board ship for obtaining a sea temperature profile from the surface down to a predetermined depth. Mechanical models consist of a bronze torpedo- shaped instrument which is lowered and recovered by means of a winch, length of wire veered being dependent on ship's speed. The record is etched onto a smoked glass slide by a stylus attached to a bimetallic temperature sensor.

After recovery the slide is removed from the instrument, marked with sounding details, placed in a holder against a graduated scale and read off: discontinuities and turning points are then added before the slide is lacquered to preserve the trace.

## EXPENDABLE BATHYTHERMOGRAPH

As the name implies this uses a non-recoverable probe. The equipment used can be considered in three sections:

*Expendable Probe.* This section is about 5 cm in diameter and 35 cm in length. It consists of a plastic protective cap, a probe in the shape of a small mortar bomb, a retaining pin and a plastic tube with a reel and protected contacts. Connecting the reel in the tube to a reel in the probe is a length of fine three-core copper wire which is veered when the probe is released, the twin reel system producing a steady rate of descent. On removing the retaining pin at the time of launching, a resistance thermometer housed in the hollow nose of the probe continuously transmits temperature readings via the copper wire.

*Launcher and Attached Cable. A* free-running cable enables the launcher to be positioned at various locations near the ship's side, where a successful sounding can be made. This cable connects the launcher to a junction box from which a fixed cable runs to the recorder. The launcher is a gun-like device with pistol grip, into the breech of which the probe is loaded; a cocking mechanism forces contacts into the end of the probe tube.

*Recorders.* The recording instruments consist of a chart recorder to register temperature against depth, a metal stylus which etches a trace on waxed paper and a cassette recorder which records the same information on magnetic tape. A manuscript log is also kept from which the completed XBT message is compiled for relay ashore by terrestrial or satellite communication.

A completed series of soundings identifies the movement of subsurface currents, the onset of thermoclines and long-term climatic change; the ships mainly involved in taking XBT soundings are warships, research vessels, weather ships and those involved in dedicated scientific projects such as TOGA (Tropical Ocean and Global Atmosphere Programme).